Radiation-Induced Charge Collection in Detector Arrays*
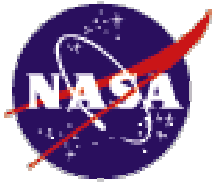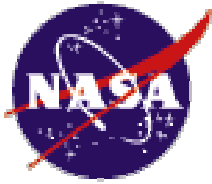
J.C.Pickel, R.A.Reed, R.Ladbury, B.Rauscher, P.W.Marshall, T.M.Jordan, B.Fodness and G.Gee

# Outline

- Background

- Ionizing Particle Environment

- Array Charge Collection Model

- Model Calibration With Test Data

- Comparison to Available Data

Radiation Effects Challenge for IR Astronomy

- **Exposure to galactic cosmic rays and solar particle events**

- **Very low noise required**
  - 10 electrons or less

- **Very long integration time required**
  - hundreds to thousands of seconds

- **Single event transients increase output level of individual pixels**
  - Transients are "latched in" until reset
  - "High" level events can be filtered
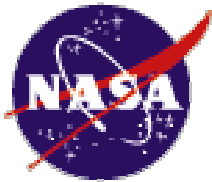 - "Low" level events increase noise
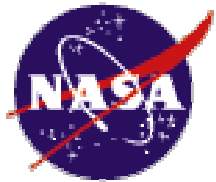
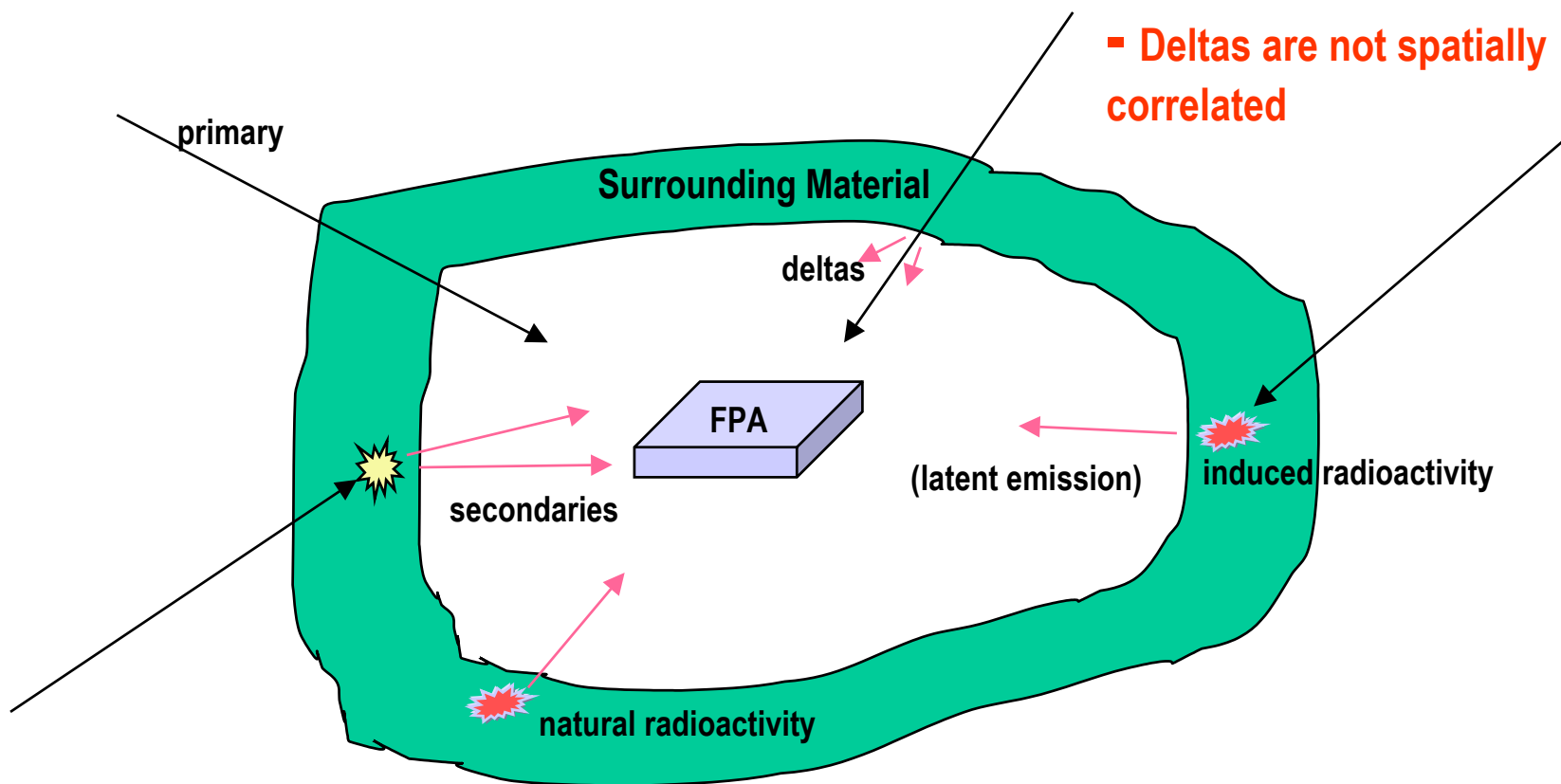# Radiation-Induced Charge in NICMOS
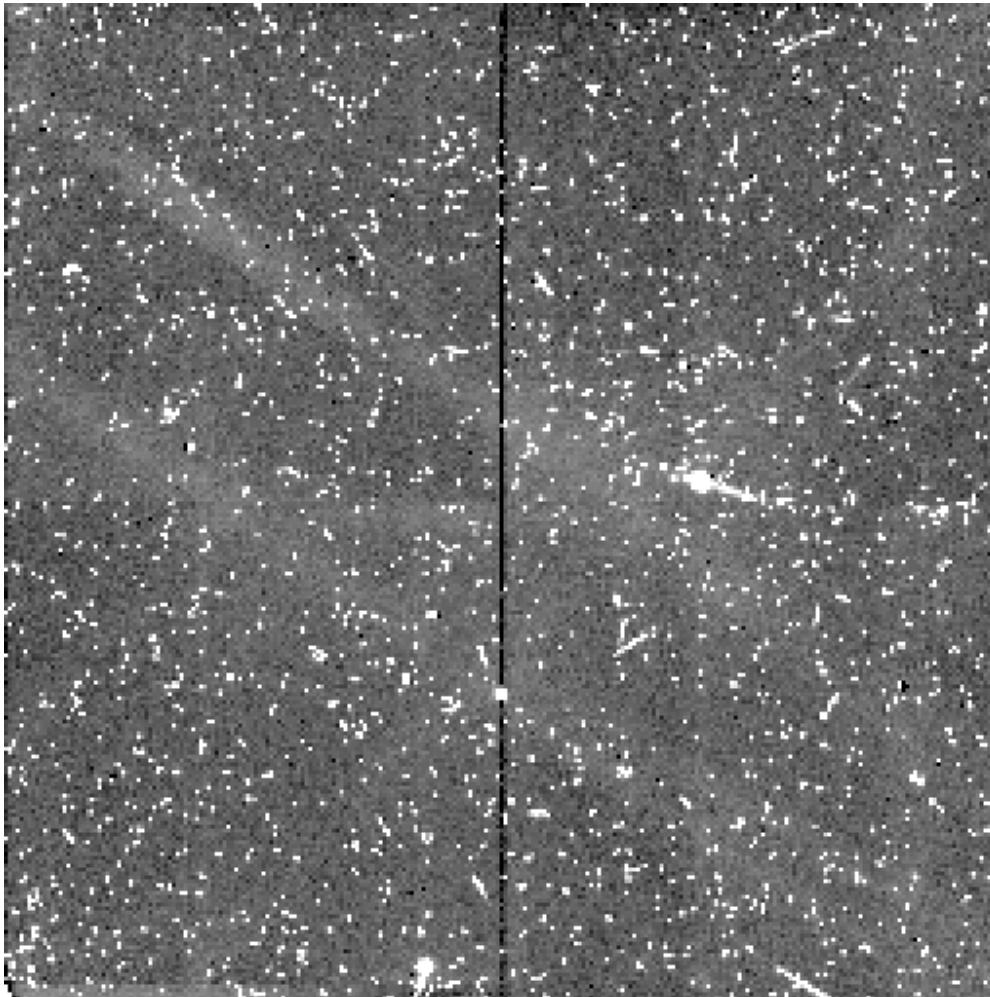
256x256 HgCdTe Array
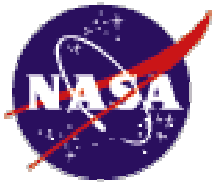
Cosmic Ray charge deposits after ~30 minutes of dark-field viewing

Ionizing Particle Impacts to FPA

- **Deltas are not spatially correlated**

primary

Surrounding Material

deltas

FPA

secondaries

(latent emission)

induced radioactivity

natural radioactivity
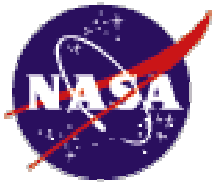
+ Secondaries and delta electrons are time coincident with primary and have limited range

Presented by J.C.Pickel, NASA/GSFC Consultant
2002 IEEE Nuclear and Space Radiation Effects Conference, Phoenix, AZ

General Approach

Space Environment → Environment Transport Calculations ↔ Secondary and Transported Primary Environment protons, electrons, neutrons, photons

Spacecraft Model and Materials →

Activation Studies → Array Charge Transport Model
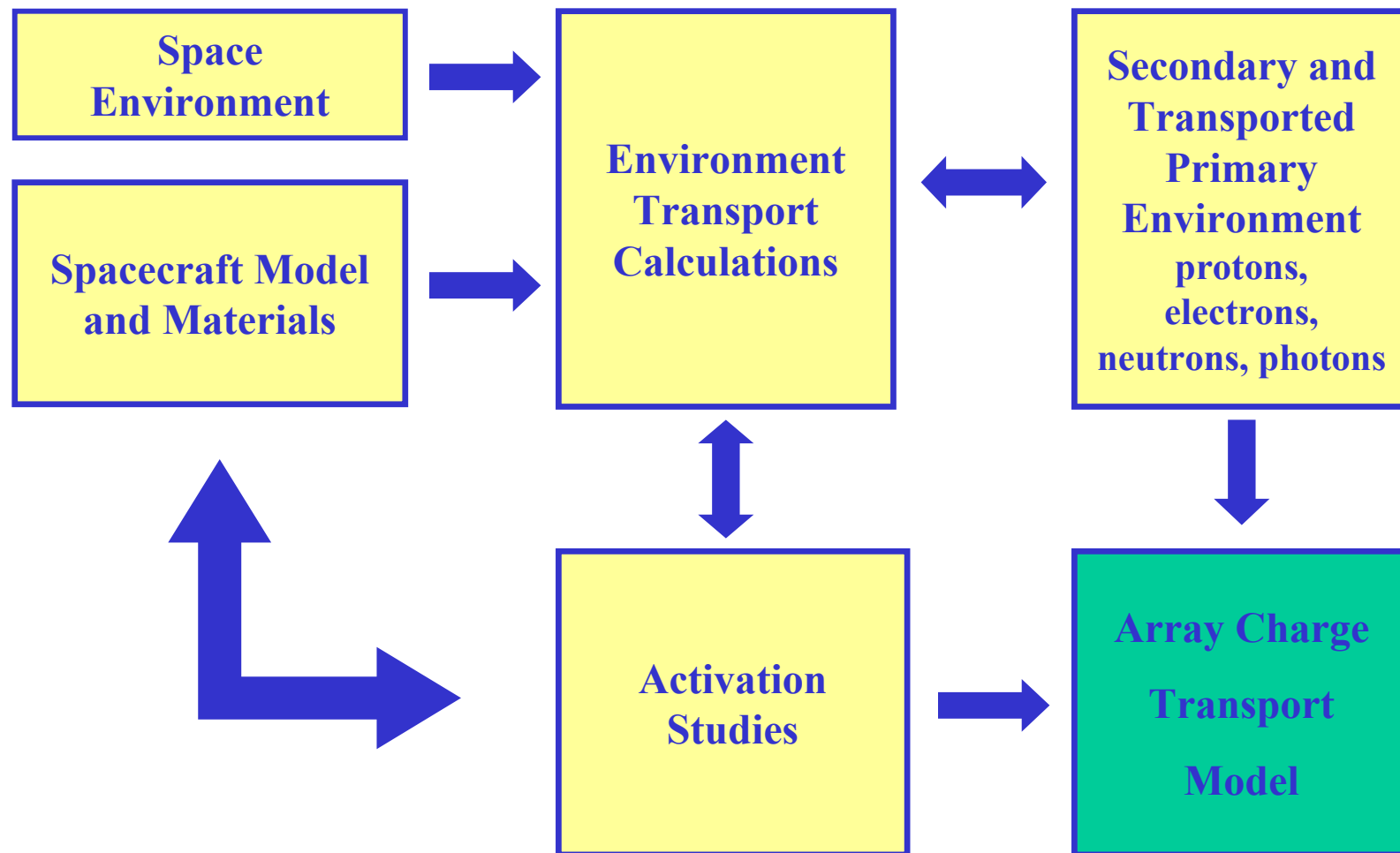
Both the Detector Array and the ROIC Contribute to Charge Collection in Hybrid FPA

Detector Array

In columns

1	2	3	4	5

Si ROIC

Depletion region (high field)
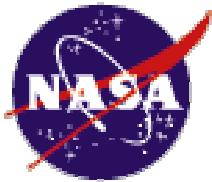
Diffusion region (low field)

Substrate (inactive)
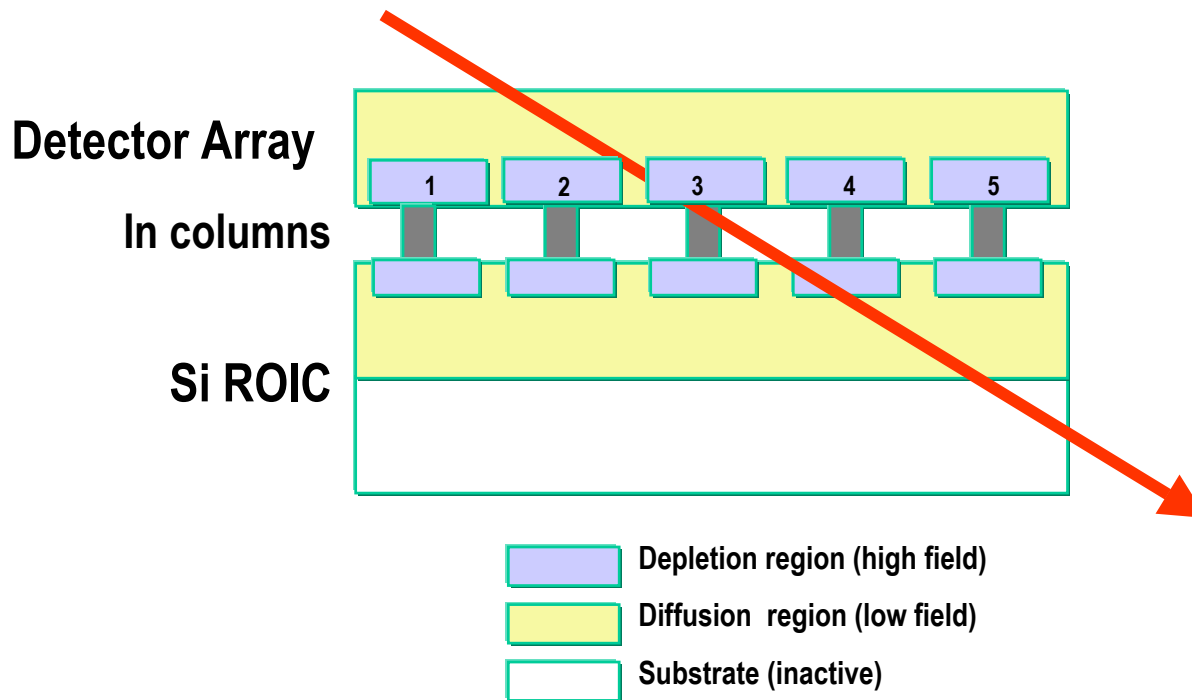
- Charge collected by drift in high-field regions
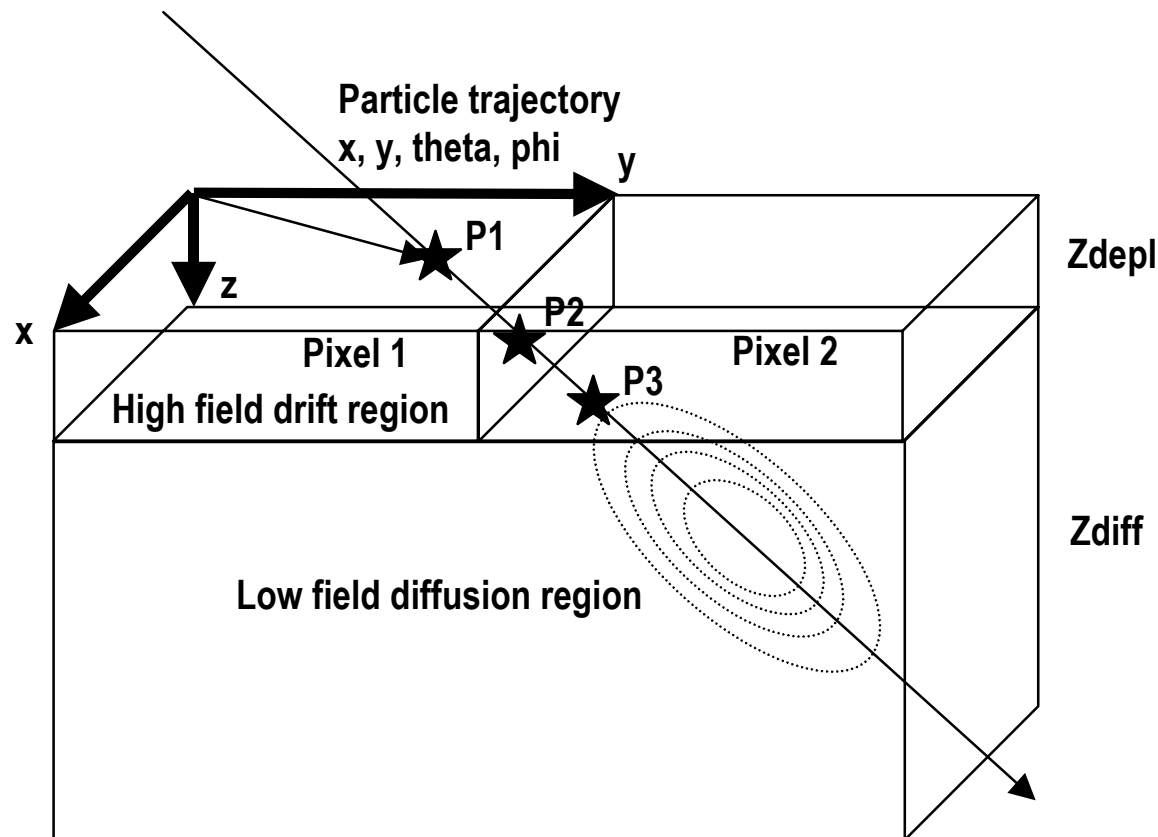- Charge collected by diffusion in low-field regions
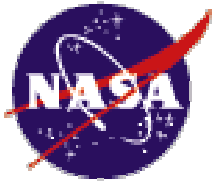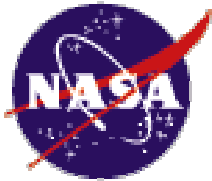
Charge Collection Modeling Approach

- **Starting point is charge collection model for proton hits to CCDs developed and validated at Aerospace Corporation**

- **Add enhancements**
  - **secondary particles generated externally and internally**
  - **activation/decay and inherent radioactivity**
  - **multiple layers**
  - **sub-regions within layers**
  - **LET variation along path**
  - **large angle scatter (electrons)**
  - **drift-assisted diffusion**

Array Charge Collection Model

Particle trajectory
x, y, theta, phi

P1

P2

P3

Zdepl

Pixel 1

Pixel 2

High field drift region
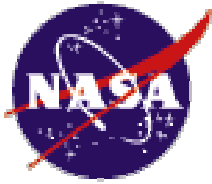
Low field diffusion region

Zdiff

y

x

z

- Initial line source based on particle LET and trajectory
- All charge that is generated in or diffuses to high-field region is collected
- Particle history ends when either collected or recombines

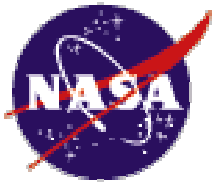# Charge Collection by Diffusion in Low Field Regions

- Analytic model by Kirkpatrick calculates charge distribution on a uniform collection surface from a line-source
  - Solves 3-D diffusion equation assuming semi-infinite medium and assuming point source at given depth
    - $Qps(x,y)$
  - Integrates $Qps(x,y)$ along line with trajectory (θ,φ) through diffusion region to effective diffusion length (L) to give surface charge density
    - $Qls(x,y,\theta,\varphi,L)$
- Charge collected by each pixel obtained by numerical integration over pixel area at diffusion-depletion boundary
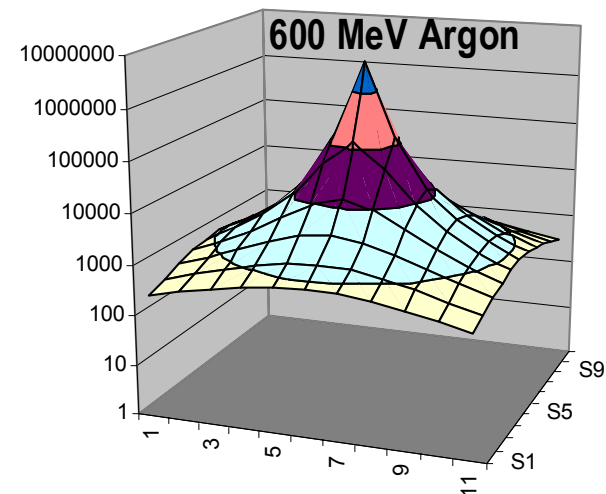 - $Qn,m = \Sigma\Sigma Qls(x,y)dxdy$

Charge Collection by Drift and Diffusion in Moderate Field Regions
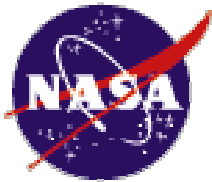
Drift   **Diffusion**
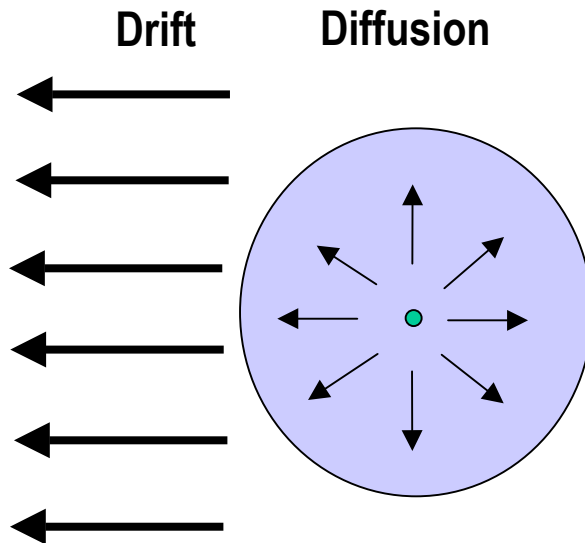
- **Hybrid Monte Carlo solution to transport equation**

- **3-D random walk with spatially dependent drift**

- **Follows approach used by Sai-Halasz to model alpha particle effects in ICs**

Charge Spread for Various Particles

Presented by J.C.Pickel, NASA/GSFC Consultant
2002 IEEE Nuclear and Space Radiation Effects Conference, Phoenix, AZ
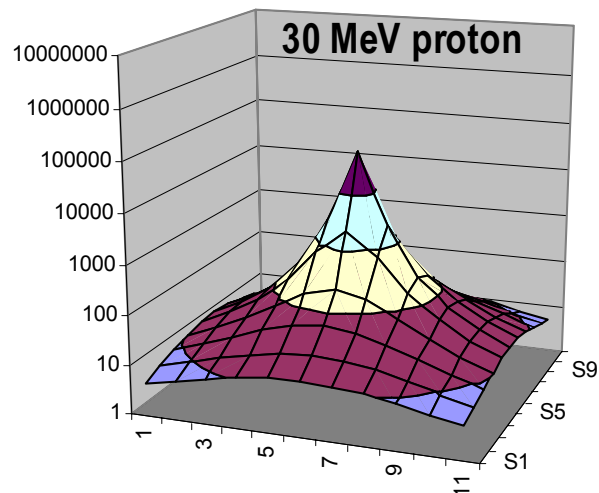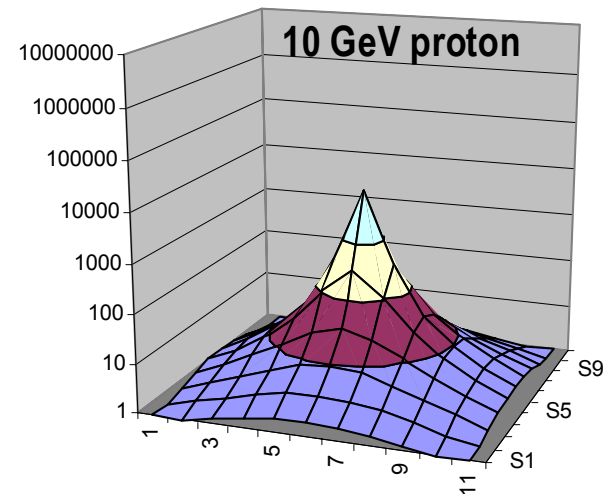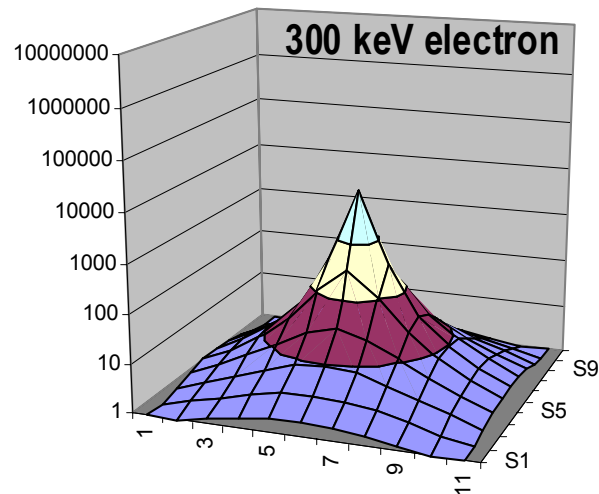
Simulation for Effect of Angle
20 MeV Proton Hits

Pitch = 30 um

Zdepl = 1 um

Zdiff = 5 um

Theta = 0

0	1	1	1	1	1	1	1	0	0
1	1	2	3	3	3	2	1	1	0
1	2	4	8	11	8	4	2	1	1
1	3	8	39	120	37	8	3	1	1
1	3	12	125	5348	111	11	3	1	1
1	3	8	37	106	35	8	3	1	1
1	2	4	8	11	8	4	2	1	1
1	1	2	3	3	3	2	1	1	0
0	1	1	1	1	1	1	1	0	0
0	0	1	1	1	1	1	0	0	0

Theta = 60

1	1	2	2	2	2	2	1	1	1
1	2	3	5	5	5	3	2	1	1
2	3	7	12	16	12	6	3	2	1
2	5	14	51	112	49	14	5	2	1
3	7	23	232	10389	206	22	6	3	1
3	6	19	117	639	108	18	6	3	1
2	4	10	23	33	22	9	4	2	1
2	3	4	7	8	7	4	3	1	1
1	2	2	3	3	3	2	2	1	1
1	1	1	1	2	1	1	1	1	1

Theta = 80

2	3	4	4	4	4	4	3	2	1
3	4	6	8	9	8	6	4	3	2
4	7	13	20	23	20	12	7	4	3
6	12	27	66	102	64	26	12	6	3
7	17	54	335	15035	307	51	17	7	4
8	19	66	647	16594	576	63	18	8	4
7	15	42	168	436	159	41	15	7	4
5	10	20	39	51	38	19	10	5	3
4	6	10	14	15	14	9	6	4	2
3	4	5	6	7	6	5	4	3	2

Theta = 89

3	3	3	3	3	3	3	3	3	2
4	4	4	5	5	5	4	4	4	3
5	6	6	7	7	7	6	5	5	4
6	8	9	10	11	10	9	8	6	5
9	11	15	18	19232	18	15	11	9	7
12	17	26	41	38440	40	25	17	12	9
17	27	48	133	19524	126	47	26	17	12
23	40	83	358	18050	330	81	39	23	15
31	55	128	633	25429	580	123	54	30	19
38	73	176	915	28175	837	170	71	38	23

Presented by J.C.Pickel, NASA/GSFC Consultant

2002 IEEE Nuclear and Space Radiation Effects Conference, Phoenix, AZ

Typical Simulation Result

100x100 array, pitch=20 um

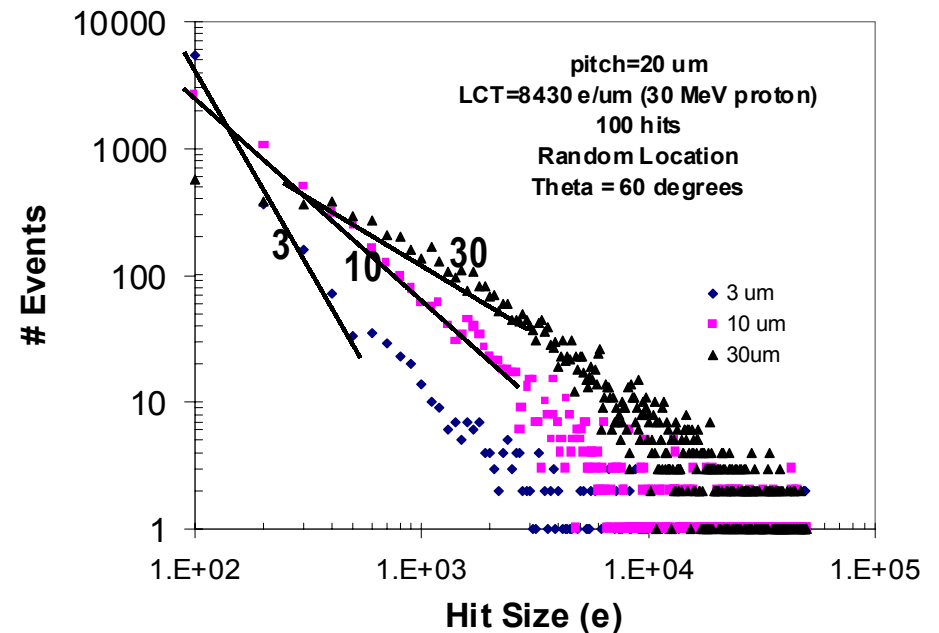HgCdTe, Zdepl=1 um, Zdiff=10 um

100 random hits, omnidirectional
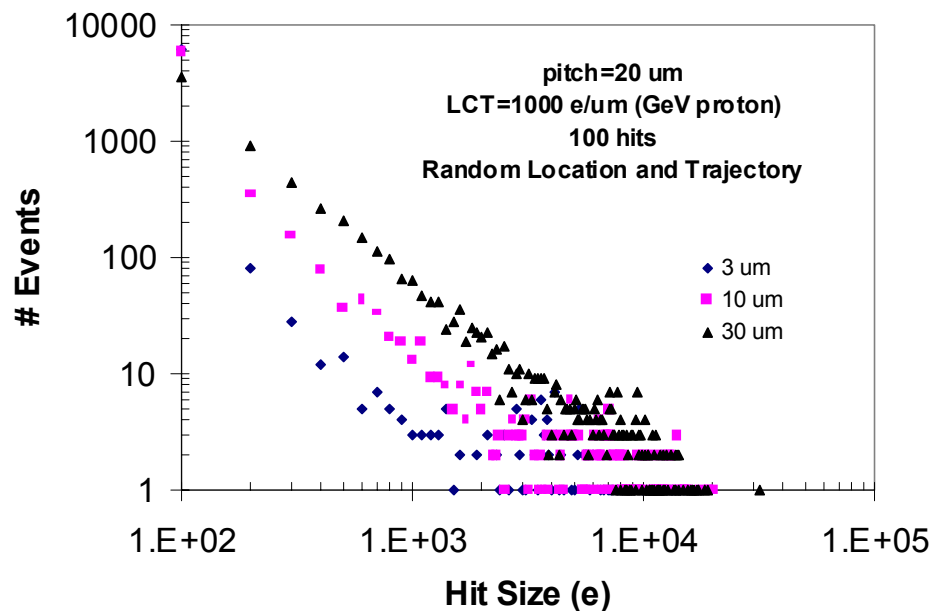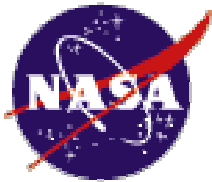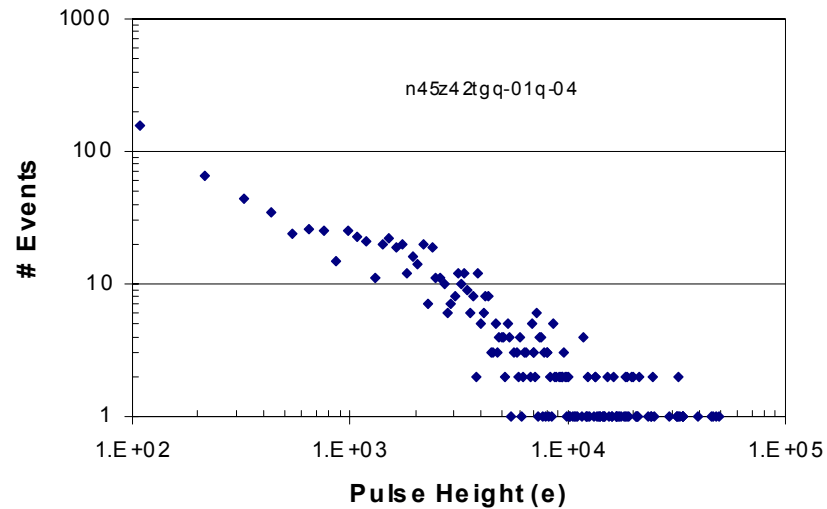
GeV protons
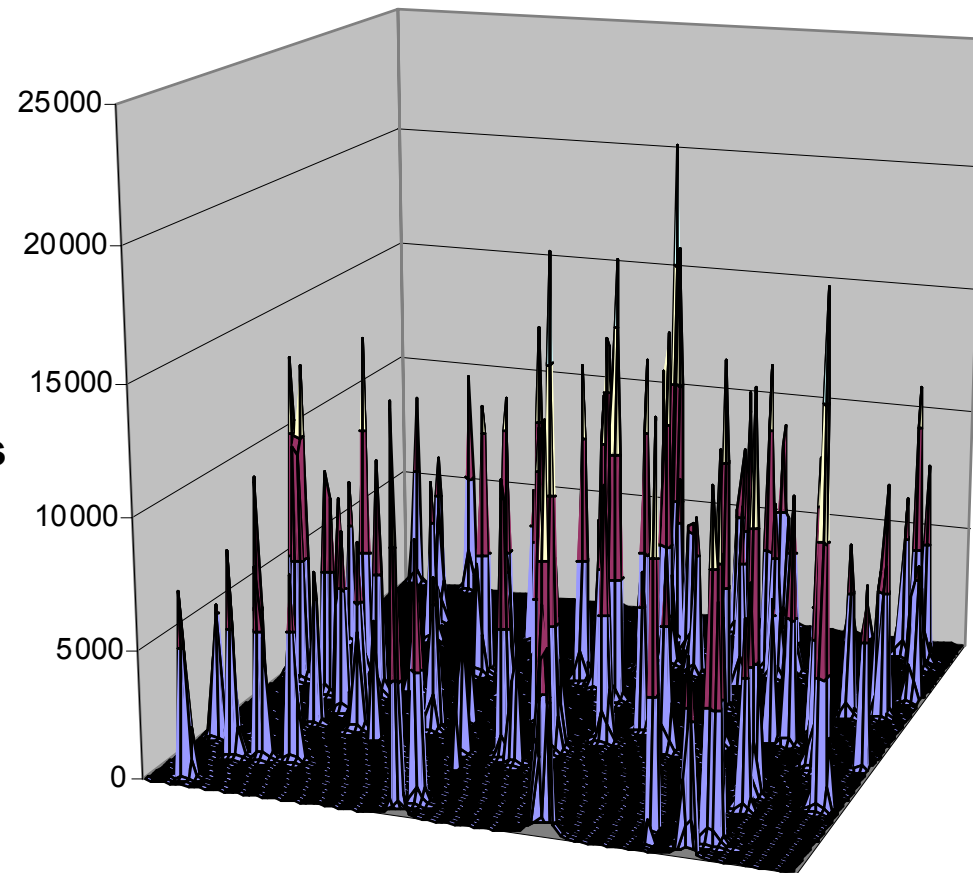
Pulse Height Distribution

Compare test data to simulation to infer model parameters

- Qav and Qmax related to charge collection volume geometry

- PHD shape dependence in cross-talk tail related to diffusion
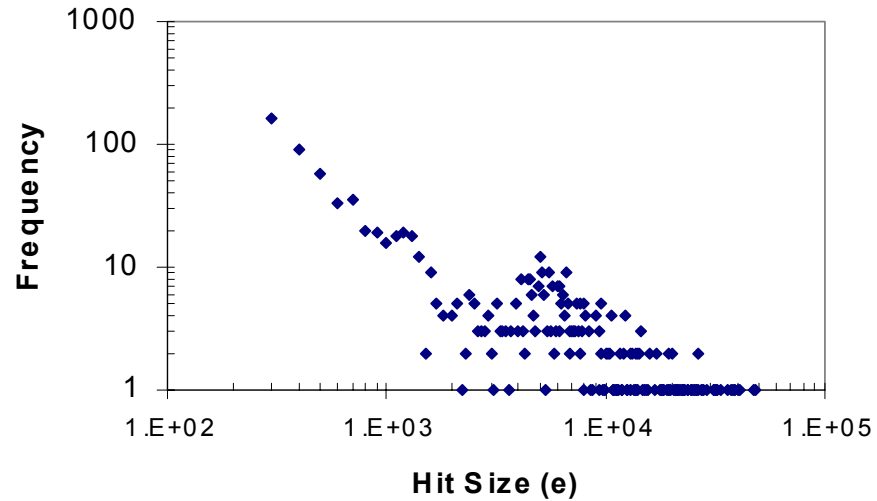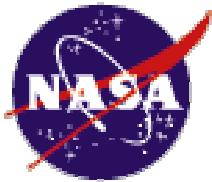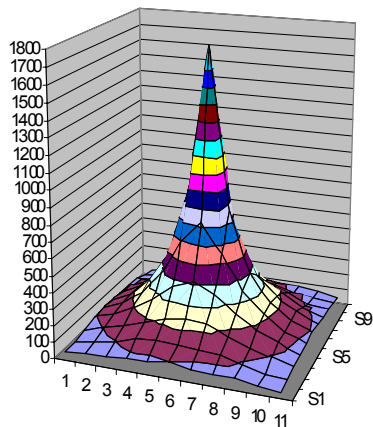layer thickness

Comparison to NICMOS Data

On-Orbit Data

n45z42tgq-01q-04

(scatter plot: # Events vs Pulse Height (e), log-log scale, x-axis from 1.E+02 to 1.E+05, y-axis from 1 to 1000)

Simulation

(scatter plot: Frequency vs Hit Size (e), log-log scale, x-axis from 1.E+02 to 1.E+05, y-axis from 1 to 1000)
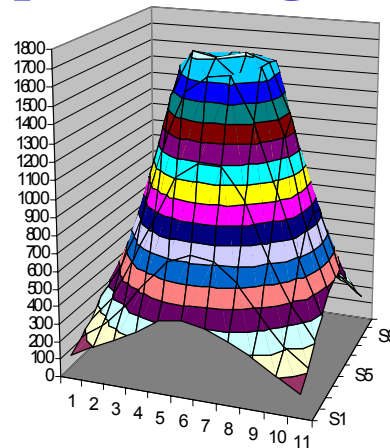
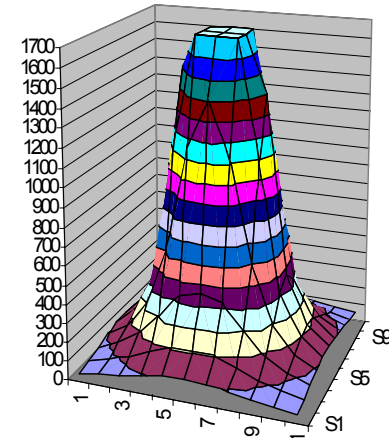# Comparison to APS Data
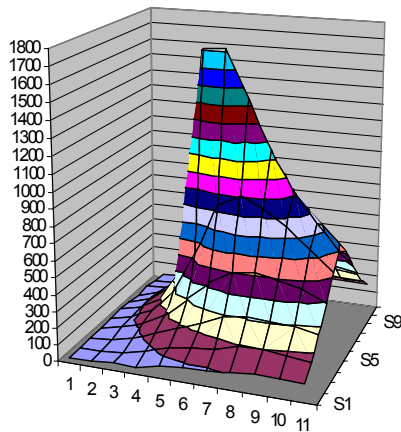## 600 MeV Ar at 0 and 60 Degrees
2 pixel designs
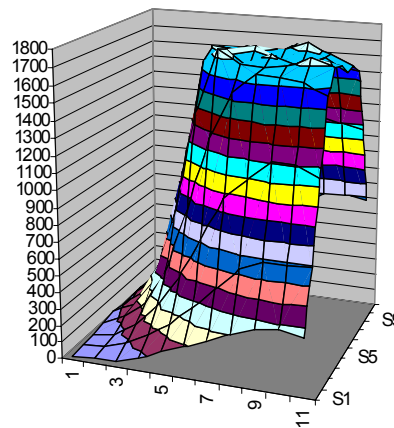

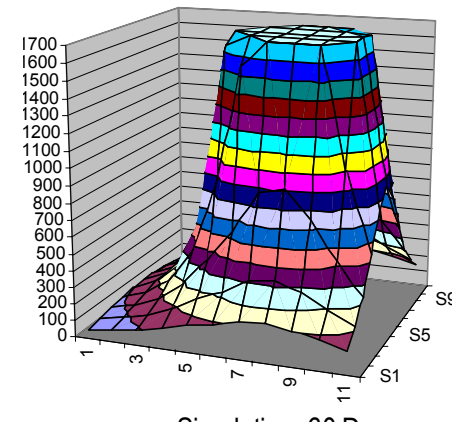Quad 1 Data, 0 Deg

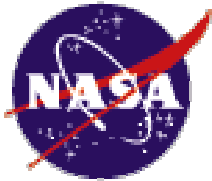Quad 2 Data, 0 Deg

Simulation, 0 Deg

Quad 1 Data, 60 Deg

Quad 2 Data, 60 Deg

Simulation, 60 Deg

Summary

- **Simulation tools for charge collection in detector arrays have been developed using a combination of analytical and Monte Carlo approaches**

- **Simulation addresses:**
  - secondary particles and radioactivity
  - multiple layers and sub-regions within layers
  - variation of LET
  - secondary electron scattering
  - drift
  - free-field diffusion
  - field-assisted diffusion

- **Model parameters can be calibrated with experimental data**

- **Applicable to all semiconductor detector arrays**